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Effects of Planting Date on Yield, Yield Components, and Chemical Compositions in Rice Plants[1]

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ABSTRACT: Rice cultivars, Tainung 67 (TNG 67) (Japonica) and Taichung Sen 10 (TCS 10) (Indica), were grown in six different times under natural conditions at the experimental farm of the Taiwan Agricultural Research Institute (TARI) at Wufeng, Taichung to investigate the relationships among climatic factors (air temperature, relative humidity, solar radiation and precipitation.), yield and chemical compositions (amylose, free sugar, crude protein and ash), and to establish the forecasting model for rice production. The climatic factors from the second crop season of 1997 to the first crop season of 1998 were investigated in Taichung area. The results indicated the trends of changes in temperature, solar radiation and precipitation were from high to low in the second crop season while from low to high was found in the first crop season. The relative humidity ranged between 80% and 96% for both crop seasons. In the second crop season, the late transplanted TNG 67 had higher yield (6,182.8 and 6,013.7 $kgha^{-1}$) and higher chemical composition contents (amylose and sugar) while the early transplanted TCS 10 had higher yield (6,208.8 and 6,136.5 $kgha^{-1}$) and lower chemical compositions. In the first crop season, TNG 67 and TCS 10 had higher yield of 6386.5 $Kgha^{-1}$ and 6328.7 $kgha^{-1}$ under early transplanting condition. Both cultivars transplanted in later dates produced higher chemical composition contents of crude proteins and ash (P, Ca, Fe, etc.). The chemical compositions of TCS 10 are higher than those of TNG 67 except the free sugar in the first and the second crop seasons. There were significant differences among transplanting dates and cultivars for yield, yield components and chemical compositions. In the first and the second crop seasons, the yield and the amylose of both cultivars showed highly correlated with the following climatic factors: X_1 (accumulated temperature), X_2 (mean temperature), X_5 (solar radiation) and X_7 (mean precipitation). The following equations of $Y_1 = 60.15 + 0.42 * X_2$ and $Y_1 = 55.76 + 0.57 * X_2$ were derived to express the relationship between the yield ($kgha^{-1}$) and the climatic factors during the tillering period in the first crop season for TNG 67 and TCS 10 respectively. The relationship between the yield and the climatic factors during the tillering period in the second crop season for TNG 67 and TCS 10 can be expressed as $Y_1 = 32.72 - 0.91 ** X_2$ and $Y_1 = 54.62 + 0.81 ** X_2$, respectively. The relationship between the amylose content (Y_2: %) and the climatic factors during the grain filling period in the first crop season of 1998 for TNG 67 and TCS 10 can be represented as $Y_2 = 78.26 - 0.93 ** X_2$ and $Y_2 = 12.68 - 8.81 * X_2$, respectively. The relationship between the amylose content and the climatic factors during the grain filling period in the second crop season of 1997 can be expressed as $Y_2 = 10.32 - 0.85 ** X_1$ and $Y_2 = 6.26 - 0.65 * X_1$, respectively.

Keywords: Climatic factors, Chemical composition, Rice, Yield.

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INTRODUCTION

Rice is one of the most important food crops in Taiwan. The participation of Taiwan into the World Trade Organization (WTO) may cause a significant impact on the crop production. The majority of the rice farmers will be suffered from the impact of WTO on the rice industry. The government would have not only to protect rice industry but also to adjust the policy of rice related research project to solve the rice production (quantitative and qualitative) in Taiwan. In this report, the rice production is presented by the yield, yield component, and chemical compositions (amylose, free sugar, crude protein, ash etc.) in relation to climatic factors. We have to understand how rice plant responding to climatic factors before changing any policy. Asghari and Hanson (1984) reported that crop yield depends on the climatic factors that play significant roles in enhancing yield potential. In addition, Resurreccion *et al.* (1977) indicated that the climatic factors could affect the grain quality of rice. For the past years, the study of rice production in Taiwan was concentrated on variety improvement, physiology and cultivation studies. However, there have been few researches on the effect of the climatic factors on the rice production and the yield-forecast test. Nonetheless, the yield forecast test always used various varieties and experimental methods during the experimental process. Therefore, no consistent data have shown the rice production-climate system in Taiwan.

The objectives of this research are: 1) To examine the effect of climatic factors on the yield, the yield components, the chemical composition and then to determine the rice production-climate system (cropping system) in the Taichung area performed under current climatic conditions. 2) To develop a set of models using available climatic data to avoid weather damage and predict rice production.

MATERIAL AND METHODS

Field experiments were conducted at the experimental farm of the Taiwan Agricultural Research Institute (24°02'N. 120°40'E. elevation 85 m) from the second crop season of 1997 to the first crop season of 1998 to investigate the relationships between the climatic factors (air temperature, relative humidity, solar radiation and precipitation.), and the yield, the yield component and the chemical compositions (amylose, free sugar, crude protein, and ash) of rice grain. Rice varieties Tainung 67 (Japonica) and Taichung Sen 10 (Indica) were grown at six different times in every crop season under natural conditions. Every crop season was scheduled to transplant 6 times at approximately 5-10 day interval. The six transplanting dates were July 22, July 28, August 2, August 7, August 13 and August 19 in the second crop season while those for the first crop season were January 26, February 5, February 12, February 18, February 24 and March 2, respectively.

The experiment was a randomized complete block design in a split-plot treatment arrangement with four replicates. Planting dates and cultivars were main and subplot factors, respectively. Statistical analysis consists of the testing for planting date effects on the yield, yield component, and chemical compositions calculating least significant difference at $P \leqq 0.05$. Kuo and Tsai (2000) indicated that the climatic factors showed significant effect on the yield and the yield component at four major rice growth stages (tillering, panicle formation, booting and ripening stage). In general, the chemical composition of milled rice such as amylose, free sugar, crude protein and mineral nutrients (Ca, Fe, P etc.) were significantly influenced by the climatic factors (air temperature, solar radiation, etc.) during the grain filling period (Resurrection *et al.* 1997, Asaoka *et al.*, 1985 a, b). We postulated the equations to express the relationship among the yield, the amylose and the climatic factors in the four major rice growth stages (tillering, panicle formation, booting and ripening stage). We also proposed the equations to show the relationship among the chemical composition and the climatic

factors during the grain filling period, therefore, we were able to obtain a prediction equation for the effect of climatic elements on the rice production. Climatic factors were recorded daily. The rice grain was milled. Its amylose (Jualino *et al.* 1981), free sugar, crude proteins and ash content were analyzed (A. O. A. C. 1984). The free sugar was extracted with 80% alcohol and then determined by phone-sulfuric acid (Dubois *et al.*, 1956). The protein content was calculated by N% × 5.95. The Ca, Fe and P content were analyzed by using Induced Coupled Plasma (ICP) analyzer.

RESULTS AND DISCUSSION

Changes of Climatic Factors during the Experimental Period

An investigation of the climatic factors in the Taichung area from the second crop season of 1997 to the first crop season of 1998 indicated that the trend of changes in monthly mean meteorological factors (air temperature, relative humidity, solar radiation, and precipitation) were varying from high to low in the second crop season and from low to high in the first crop season (Fig. 1).

Mean air temperature, solar radiation, and precipitation during the transplanting period (Jul. 22 ~ Aug. 19) in the second rice crop season (Jul. 22 ~ Dec. 16) were generally high. As the mean air temperature was between 28.1 ~ 29.5 ℃, the maximum temperature was ranged between 32.6 and 34.4 ℃, the minimum temperature was between 24.2 and 25.3 ℃, the solar radiation was ranging from 12.3 ~ 13.8 MJm^{-2} and the precipitation reading was from 5.6 ~ 11.1 mm, respectively. These climatic factors (temperature, solar radiation, and precipitation) were decreased through the tillering, panicle formation, booting, heading stage and grain filling period to the maturity stage (Nov. 8 ~ Dec. 10). The daily mean temperature was between 22.3 and 19.1 ℃, the daily maximum temperature was from 23.8 to 33.5 ℃, the daily minimum temperature was from 13.9 to 18.5 ℃, the solar radiation was from 7.4 to 10.6 $MJm^{-2}day^{-1}$ and there was no precipitation during the season. In the transplanting period of the first crop season (Jan. 26 ~ Mar. 2), the mean temperature, the solar radiation and the precipitation were low. As the mean temperature is between 19.6 ℃ and 21.8 ℃ with the maximum in the range of 23.3 ℃ ~ 26.6 ℃ and the minimum in the range of 12.4 ℃ to 16.4 ℃. The solar radiation was between 1.22 and 8.20 $MJm^{-2}day^{-1}$ and the precipitation was ranged from 0 to 46.0 mm. After the tillering stage, the climatic factors in temperature, solar radiation and precipitation were increased with the highest reading at the maturity stage (mean: 28.5 ~ 29.3 ℃, max: 31.4 ~ 32.7 ℃, min: 23.2 ~ 24.7 ℃, mean: 11.4 ~ 12.3 $MJ^{-2}day^{-1}$, 4.8 ~ 17.5 $mmday^{-1}$) for the growing period of the two varieties TNG 67 and TCS 10.

Heavy rainfall due to the storm was recorded at the seedling stage in July and the tillering stage in August in the second crop season that reduced the panicle number, decreased the percentage of the ripened grains and the 1000-grain weight. Also, the cold front at seedling stage in February and the Baiu front during the grain filling period decreased the grain yield in the first crop season.

Effect of Transplanting Date on the Yield Characteristics

The effect of transplanting date on the yield components of TNG 67 and TCS 10 are shown in Table 1 and Table 2. In the second crop season, the later transplanted TNG 67 showed higher yield than the earlier one (6013.7 and 6182.8 $kgha^{-1}$). The earlier transplanted TCS 10 also showed higher yield (6136.5 and 6208.8 $kgha^{-1}$). There is significant difference for grain yield transplanted on different dates. At the tillering stage and the grain filling period, the later transplanted TNG 67 received both lower air temperature (mean 25.8 ~ 26.8 and 21.3 ~ 25.6 ℃) and lower solar radiation (7.2 ~ 9.10 $MJm^{-2}day^{-1}$ and 6.7 ~ 8.4 MJm^{-2} day^{-1}). The lower air

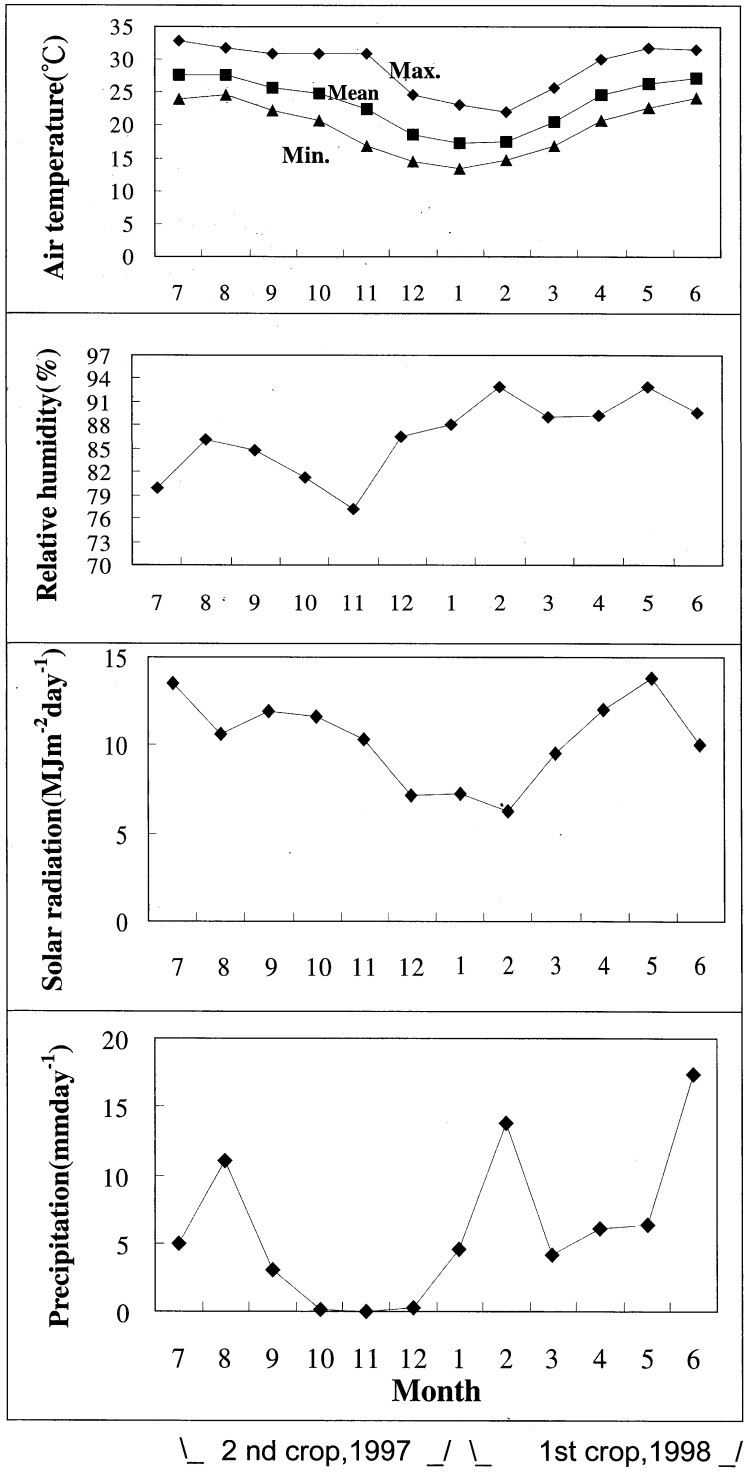

Fig 1. Change of monthly air temperature, relative humidity, solar radiation and precipitation in Taichung area.

Table 1. Effect of transplanting date on the yield and yield components of rice in the second crop of 1997

Transplanting date (D_1, D_2....D_6) - Harvest date (H_1, H_2....H_6) (month/day)	Yield (kg / ha)	Panicles / hill	Spikelets / panicle	Ripened grain (%)	1,000-grain-weight (g)
Tainung 67					
D_1 (7/22) - H_1 (11/11)	5235.2e	14.35d	101.43ab	76.57c	23.66c
D_2 (7/28) - H_2 (11/18)	5488.5d	14.40d	99.58b	77.21c	25.15b
D_3 (8/2) - H_3 (11/22)	5774.3c	14.84d	104.69a	77.84bc	24.15c
D_4 (8/7) - H_4 (11/28)	5952.1b	15.79c	92.31c	79.76ab	25.70a
D_5 (8/13) - H_5 (12/6)	6182.8a	16.63b	88.46d	81.72a	25.33ab
D_6 (8/19) - H_6 (12/13)	6013.7b	17.26a	94.72c	80.47a	24.03c
Taichung Sen 10					
D_1 (7/22) - H_1 (11/11)	6208.8a	17.89a	90.41d	81.32a	24.55a
D_2 (7/28) - H_2 (11/18)	6136.5a	17.23b	93.79c	80.23a	23.69b
D_3 (8/2) - H_3 (11/24)	5979.0b	15.94c	98.65b	78.45b	23.84ab
D_4 (8/7) - H_4 (11/30)	5651.6c	15.56c	100.53b	77.69b	23.22b
D_5 (8/13) - H_5 (12/8)	5328.0d	14.72d	106.27a	75.35c	22.43c
D_6 (8/19) - H_6 (12/16)	5125.4e	13.90e	108.74a	73.73c	21.74c

Means followed by the same letter within each column were not significant different (p = 0.05) by Duncan's MRT.

Table 2. Effect of transplanting date on the yield and yield components of rice in the first crop of 1998

Transplanting date - harvest date (month/day)	Yield (kg / ha)	Panicles / hill	Spikelets / panicle	Ripened grain (%)	1,000-grain-weight (g)
Tainung 67					
D_1 (1/26) - H_1 (6/12)	6386.5a	17.52a	87.40d	81.92ab	25.61a
D_2 (2/5) - H_2 (6/17)	6263.2b	16.84b	91.36bc	82.20a	25.19a
D_3 (2/12) - H_3 (6/22)	5940.7c	16.20c	90.69cd	81.53ab	24.88a
D_4 (2/18) - H_4 (6/25)	5678.6c	15.76c	94.79b	79.81bc	23.76bc
D_5 (2/24) - H_5 (6/28)	5211.4e	13.65d	102.52a	78.30c	23.87b
D_6 (3/2) - H_6 (7/1)	4960.8f	12.88e	104.35a	77.95c	22.94c
Taichung Sen 10					
D_1 (1/26) - H_1 (6/16)	6328.7a	16.84a	89.77e	81.85a	25.43a
D_2 (2/5) - H_2 (6/21)	6146.8b	16.23ab	91.78de	81.34ab	24.89ab
D_3 (2/12) - H_3 (6/25)	5887.5c	15.67b	94.49d	81.28ab	24.21b
D_4 (2/18) - H_4 (6/28)	5534.0d	14.89c	98.31c	79.89bc	23.40c
D_5 (2/24) - H_5 (6/30)	5258.3e	13.20d	106.74b	78.95c	22.70c
D_6 (3/2) - H_6 (7/2)	4887.4f	11.95e	109.97a	78.63c	22.87c

Means followed by the same letter within each column were not significant different (p = 0.05) by Duncan's MRT.

temperature and solar radiation were beneficial to the tillering and the grain filling, and subsequently resulted in higher grain yield. Therefore, the panicles per hill, the percentage of the ripened grain and the 1000-gain weight were higher and were almost significantly different from other yield components under different

transplanting dates. The early transplanted TCS 10 received higher air temperature (mean: 26.7 ~ 28.6 ℃) and solar radiation (11.4 ~ 14.6 $MJm^{-2}day^{-1}$) at the tillering stage, and also received higher temperature (26.9 ~ 28.4 ℃) and solar radiation (11.2 ~ 13.4 $MJm^{-2}day^{-1}$) at the grain filling period. The higher air temperature and solar radiation were considered to be beneficial to the tillering ability and number per hill, as well as yield components (except spikelets per panicle) of the rice crop (Tsai, 1993).

In the first crop season, both TNG 67 and TCS 10 rice varieties receiving earlier transplanting treatment showed higher yield of 6386.5 $kgha^{-1}$ and 6328.7 $kgha^{-1}$, respectively which was significantly different from that of later transplanting treatments. The yield components in panicle $hill^{-1}$, the percentage of the ripened grain and the 1000-grain weight were also higher than those from the later transplanting treatments. The later transplanted rice produced lower yield due to the decrease in the percentage of the ripened grains and the 1000-grain weight caused by the heavy rainfall of the Baiu (448.0mm) and the lower solar radiation (4.8$MJm^{-2}day^{-1}$) during the grain filling period in June.

The spikelets per panicle were compensated by the panicles per hill, so it was difficult to evaluate the responses of the spikelets and the panicle to the climatic factors.

The main effects of the transplanting dates and the cultivar were significantly different for all of the yield characteristics (yield, yield components) except the percentage of the ripened grain in the first crop season (Table 3). The interaction between the transplanting date and the cultivar was significantly different for all of the yield characteristics in the second crop season, but it was not significant for any of the yield characteristics in the first crop season.

Table 3. Mean square values of main effects and interactions for yield and yield component of rice plants during the 2nd crop of 1997 and the 1st crop of 1998

Effect	df	Yield (kg/ha)	Panicles/hill	Spikelets/panicle	Ripened grain (%)	1000-grain weight (g)
2nd crop, 1997						
Transplanting date (D)	5	88210.36***	0.94**	56.17***	3.82*	2.82***
Rep within D	3	6942.26	0.05	2.13	2.10	0.18
Rep × D	15	4719.73	0.19	2.30	1.53	0.29
Cultivar (C)	1	13575.38	1.25*	97.87***	17.23***	26.17***
D × C	5	102564.20***	15.13***	285.24***	47.51***	7.15***
1st crop, 1998						
Transplanting date (D)	5	16572.41***	27.46***	342.46***	25.46***	9.14***
Rep within D	3	226.41	0.24	1.39	0.25	0.08
Rep × D	15	2089.39	0.29*	6.48	2.10	0.22
Cultivar (C)	1	44158.14	6.26	142.45**	0.06	3.28*
D × C	5	7642.38	0.07	5.20	0.47	0.24

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

The Effect of the Transplanting Date on the Chemical Compositions

In the second crop season, the two rice varieties with later transplanted treatment had higher chemical compositions in amylose and sugar while the earlier ones had higher crude protein and ash contents (Table 4). Resurreccion *et al.* (1977) showed that the amylose contents of the rice grains was negatively correlated with

Table 4. Effect of transplanting date on the chemical compostion of rice in the second crop of 1997

Transplanting date (D_1, D_2....D_6) - Harvest date (H_1, H_2....H_6) (month/day)	Amylose (%)	Free sugar (%)	Crude protein (%)	Ash (%) (Ca, Fe, P, etc.,)
Tainung 67				
D_1 (7/22) - H_1 (11/11)	15.36b	0.71c	7.72a	0.52a
D_2 (7/28) - H_2 (11/18)	16.40ab	0.81bc	7.49ab	0.45ab
D_3 (8/2) - H_3 (11/22)	16.21ab	0.79bc	7.43ab	0.42b
D_4 (8/7) - H_4 (11/28)	16.58ab	0.83b	7.45ab	0.40b
D_5 (8/13) - H_5 (12/6)	17.19ab	0.86ab	7.20b	0.41b
D_6 (8/19) - H_6 (12/13)	17.85a	0.92a	6.76c	0.28c
Taichung Sen 10				
D_1 (7/22) - H_1 (11/11)	16.72c	0.65c	8.59a	0.59a
D_2 (7/28) - H_2 (11/18)	17.87bc	0.70c	8.24ab	0.58a
D_3 (8/2) - H_3 (11/24)	17.99bc	0.77b	7.76bc	0.55ab
D_4 (8/7) - H_4 (11/30)	18.74ab	0.75b	7.55c	0.48b
D_5 (8/13) - H_5 (12/8)	18.81ab	0.83a	7.32cd	0.37c
D_6 (8/19) - H_6 (12/16)	19.85a	0.86a	7.00d	0.39c

Means followed by the same letter within each column were not significantly different (p = 0.05) by Duncan's MRT.

the air temperature (r = -0.871**) during the 40-day period after heading. An increase in the amylose content of the rice grains with the later transplanting date treatment (D_6) was probably due to the lower temperature (20.4 ~ 23.6 ℃) thus increased the accumulation of the amylose contents (TNG 67: 17.85%, TCS 10: 19.85%) in the grain filling period in the second crop season. On the other way, an increase in the crude protein content in the rice with the early transplanting treatment (D_1, D_2) might be caused by the warmer temperature (24.2 ~ 26.4 ℃) during the grain filling period. Kataoka (1975) also indicated that the protein of rice grain increased under the higher temperature condition during the grain filling period. There were significant differences between D_1 and D_6 in two cultivars (Tainung 67, Taichung Sen 10) for amylose (D_1: 15.36%, 16.72%, D_6:17.85%, 19.85%), free sugar (D_1: 0.71%, 0.65%, D_6: 0.92%, 0.86%), crude protein (D_1: 7.72%, 8.59%, D_6: 6.76%, 7.00%) and ash (D_1: 0.52%, 0.59%, D_6: 0.28%, 0.39%). The chemical compositions of the TCS 10 were higher than those of the TNG 67 except the free sugar. There were significant differences among transplanting dates and cultivars for chemical compositions. But the date (D) × cultivar (C) interaction was not significant for any of the evaluated chemical compositions (Table 6).

In the first crop season, the earlier transplanted (D_1, D_2) rice of both varieties had higher chemical compositions. For example, the rice transplanted on Jan. 26 (D_1) contained amylose and free sugar for TNG 67 and TCS 10 were 18.35, 19.64, 0.51 and 0.41, respectively. While the later transplanted treatment (D_5, D_6) produced higher crude protein (D_6: Tainung 67, 7.95%, Taichung Sen 10, 8.35%) and ash (D_6: Tainung 67, 0.48%, Taichung Sen 10, 0.49%)(Table 5). The grain filling period was lower (mean 24.9 ℃) for the earlier transplanted rice and was beneficial to the increase of the amylose and free sugar contents. The later transplanted rice had higher content of crude proteins and ash that were caused by higher air temperature (mean 27.5 ℃) during the grain filling period. The result is consistent with Resurreccion *et al.* (1977) and Katooka (1975) for amylose and protein content in response to the air temperature in the grain filling period. Consequently all the chemical compositions of the Taichung Sen 10 were higher than those of the Tainung 67

Table 5. Effect of transplanting date on the chemical compostion of rice in the first crop of 1998

Transplanting date (D_1, D_2....D_6) - Harvest date (H_1, H_2....H_6) (month/day)	Amylose (%)	Free sugar (%)	Crude protein (%)	Ash (%) (Ca, Fe, P, etc.,)
Tainung 67				
D_1 (1/26) - H_1 (6/12)	18.35a	0.51a	6.48ab	0.39ab
D_2 (2/5) - H_2 (6/17)	18.38a	0.45b	7.05ab	0.39b
D_3 (2/12) - H_3 (6/22)	17.75ab	0.42bc	7.31bc	0.41ab
D_4 (2/18) - H_4 (6/25)	17.70ab	0.43bc	7.61c	0.41b
D_5 (2/24) - H_5 (6/28)	17.28ab	0.41bc	7.64ab	0.43ab
D_6 (3/2) - H_6 (7/1)	16.62b	0.39c	7.95a	0.48a
Taichung Sen 10				
D_1 (1/26) - H_1 (6/16)	19.64a	0.41ab	7.67b	0.43a
D_2 (2/5) - H_2 (6/21)	19.48a	0.33ab	7.64b	0.45a
D_3 (2/12) - H_3 (6/25)	19.50a	0.33a	7.43b	0.44a
D_4 (2/18) - H_4 (6/28)	19.38a	0.32ab	6.67c	0.45a
D_5 (2/24) - H_5 (6/30)	19.23a	0.26b	7.68b	0.46a
D_6 (3/2) - H_6 (7/2)	19.13a	0.29b	8.35a	0.49a

Means followed by the same letter within each column were not significantly different (p = 0.05) by Duncan's MRT.

Table 6. Mean square values of main effects and interactions for chemical composition of rice grain during the 2nd crop of 1997 and the 1st crop of 1998

Effect	df	Amylose (%)	Free sugar (%)	Crude protein (%)	Ash (%)(Ca, Fe, P,etc.,)
2nd crop, 1997					
Transplanting date (D)	5	8.62***	0.06***	1.85***	0.08***
Rep within D	3	1.21	0.04	0.06	0.05
Rep × D	15	1.15	0.05	0.07	0.08
Cultivar (C)	1	38.62***	0.08***	1.84***	0.11***
D × C	5	0.21	0.04	0.25	0.04
1st crop, 1998					
Transplanting date (D)	5	9.51***	0.05**	2.18***	0.09*
Rep within D	3	0.07	0.03	0.15	0.05
Rep × D	15	0.21	0.04	0.12	0.04
Cultivar (C)	1	2.62*	0.26***	0.71*	0.05**
D × C	5	0.32	0.05	0.07	0.03

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

except the free sugar. The transplanting date (D) and the cultivar (C) treatments showed significant difference on all the chemical compositions (Table 6).

Equations to predict the yield and the Amylose Rate of the Tainung 67 and Taichung Sen 10 by using the Climatic Factors

The equations for predicting the rice yield (Y) and the amylose rate (A) related to the climatic factors in the second crop season of 1997 and the first crop season of 1998 were listed in Table 7 and Table 8, respectively. The growing period was divided into three stages: namely the tillering stage, the panicle

Table 7. Equation to express the rice yield (Y_1: $kgha^{-1}$) and amylose rate (Y_2: %) relating to the climatic factors in the second crop of 1997

Tainung 67	
Tillering stage	
$Y_1 = 32.72 - 0.91 ** X_2$	$R^2 = 0.91$
Panicle formation stage	
$Y_1 = 180.61 - 0.86 ** X_2$	$R^2 = 0.86$
Grain filling period (Heading ~ Dough stage)	
$Y_1 = 178.43 - 0.47 * X_2$	$R^2 = 0.94$
$Y_2 = 10.32 - 0.85 ** X_1$	$R^2 = 0.83$
Tainung Sen 10	
Tillering stage	
$Y_1 = 54.62 + 0.81 ** X_2$	$R^2 = 0.90$
Panicle formation stage	
$Y_1 = 18.42 + 0.86 ** X_2$	$R^2 = 0.86$
Grain filling period (Heading ~ Dough stage)	
$Y_1 = 18.65 + 0.62 * X_2$	$R^2 = 0.73$
$Y_2 = 6.26 - 0.65 * X_1$	$R^2 = 0.78$

X_1: accumulated temperature (℃), X_2: mean temperature (℃).

* and ** are significaut at 5 % and 1 % level, respectively.

Table 8. Equation to express the rice yield (Y_1: $kgha^{-1}$) and amylose rate (Y_2: %) relating to the climatic factors in the first crop of 1998

Tainung 67	
Tillering stage	
$Y_1 = 60.15 + 0.42 * X_2$	$R^2 = 0.91$
Panicle formation stage	
$Y_1 = 15.85 - 7.45 ** X_7$	$R^2 = 0.92$
Grain filling period (Heading ~ Dough stage)	
$Y_1 = 80.34 - 0.91 ** X_7$	$R^2 = 0.88$
$Y_2 = 78.26 - 0.93 ** X_2$	$R^2 = 0.92$
Tainung Sen 10	
Tillering stage	
$Y_1 = 55.76 + 0.57 * X_2$	$R^2 = 0.75$
Panicle formation stage	
$Y_1 = 2.27 + 0.48 * X_1$	$R^2 = 0.71$
Grain filling period (Heading ~ Dough stage)	
$Y_1 = 54.32 + 0.47 * X_5$	$R^2 = 0.74$
$Y_2 = 12.68 - 8.81 * X_2$	$R^2 = 0.91$

X_1: accumulated temperature (℃), X_2: mean temperature (℃), X_5: solar radiation ($MJm^{-2}day^{-1}$), X_7: precipitation ($mmday^{-1}$).

* and ** are significaut at 5 % and 1 % level, respectively.

formation stage and the grain filling stage. For the two crop seasons, the yield of both cultivars can be expressed by using one of the following climatic factors: X_1 (accumulated temperature), X_2 (mean temperature), X_3 (relative humidity), X_5 (solar radiation) and X_7 (precipitation). The following equations were derived to express the relationship between the yield (Y kgha^{-1}) and one of the climatic factors during one of tillering stage, the panicle formation stage or the grain filling stage in the second crop season of 1997.

For the TNG 67 cultivar,

$$Y_1 = 32.72 - 0.91^{**}X_2 \text{ (tillering stage)} \quad (1)$$

or $$Y_1 = 180.61 - 0.86^{**}X_2 \text{ (panicle formation stage)} \quad (2)$$

or $$Y_1 = 178.43 - 0.47^{*}X_2 \text{ (grain filling stage)} \quad (3)$$

Where Y_1 denotes the yield (kgha^{-1}) of TNG 67 and X_2 represents the mean temperature (℃) in the corresponding stage.

For the TCS 10 cultivar,

$$Y_1 = 54.62 + 0.81^{**}X_2 \text{ (tillering stage)} \quad (4)$$

$$Y_1 = 18.42 + 0.86^{**}X_2 \text{ (panicle formation stage)} \quad (5)$$

$$Y_1 = 18.65 + 0.62^{*}X_2 \text{ (grain filling stage)} \quad (6)$$

Where Y_1 denotes the yield (kgha^{-1}) of TCS 10 and X_2 represents the mean temperature (℃) in the corresponding stage.

While the relationship between the yield and the climatic factors during the tillering stage, the panicle formation stage or the grain filling stage in the first crop season of 1998 can be represented as follows:

For Tainung 67,

$$Y_1 = 60.15 + 0.42^{*}X_2 \text{ (tillering stage)} \quad (7)$$

$$Y_1 = 15.85 - 7.45^{**}X_7 \text{ (panicle formation stage)} \quad (8)$$

$$Y_1 = 80.34 - 0.91^{**}X_7 \text{ (grain filling stage)} \quad (9)$$

Where Y_1 denotes the yield (kgha^{-1}) of TNG 67 while X_2 and X_7 represents the mean temperature and the precipitation in the corresponding stage of the first crop season in 1998.

For the TCS 10 variety,

$$Y_1 = 55.76 + 0.57^{*}X_2 \text{ (tillering stage)} \quad (10)$$

$$Y_1 = 2.27 + 0.48^{*}X_1 \text{ (panicle formation stage)} \quad (11)$$

$$Y_1 = 54.32 + 0.47^{*}X_5 \text{ (grain filling stage)} \quad (12)$$

Where Y_1 denotes the yield (kg ha^{-1}) of TCS 10 and X_1, X_2, X_5 represents the accumulated temperature, the mean temperature and the solar radiation in the corresponding stage, respectively.

The relationship between the amylose content and the climatic factors during the grain filling period in the second crop season of 1997 for TNG 67 and TCS 10 can be expressed as:

$$Y_2 = 10.32 - 0.85^{**}X_1 \quad (13)$$

$$Y_2 = 6.26 - 0.65^{*}X_1 \quad (14)$$

Where Y_2 denotes the amylose content of TNG 67 and TCS 10, respectively. And X_1 is the accumulated temperature during the grain filling period.

The relationship between the amylose content and the climatic factors during the grain filling period in the first crop season of 1998 for TNG 67 and TCS 10 can be expressed as:

$$Y_2 = 78.26 - 0.93^{**}X_2 \quad (15)$$

$$Y_2 = 12.68 - 8.81^{*}X_2 \quad (16)$$

X_2 is the mean precipitation during the grain filling period.

From these derived equations, we conclude that the effects of climatic factors on the yield or the amylose content are dominated by the air temperature which is the major factor for controlling the development of the rice (Christiansen, 1986: Ehlig, 1986). Reddy *et al.* (1986) also indicated that the temperature could be used to predict the development and the growth of the grain yield.

CONCLUSION

Our experimental results have demonstrated the effect of climatic factors on the yield as well as the chemical compositions of rice plants. It also described how the rice cropping (production-climate) system in Taichung area performs under current climatic conditions. Based on the readily available data, we developed a series of equations to avoid weather damage and to forecast rice production. These equations will be tested for their reliability and suitability.

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水稻不同移植期對於產量、產量構成要素及化學組成之影響[1]

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摘要：秈粳各一品種臺中秈10號及臺農67號於本所試驗田，在自然的環境下一、二期作各分六次種植進行試驗。目的在探知氣象因子與產量及化學組成（直鏈澱粉、蛋白質及礦物質等含量）之關係。並擬建立稻作生產預測模式。據調查結果，於台中地區自1997年二期作試驗開始至1998年一期作，其氣象因子之變化，則由高至低之氣溫、日射量及雨量，而一期作之變化正好相反，即自低而高的變化。至於相對濕度的變化並不劇烈，兩期作的變化都在80 %至96%之間。粳型臺農67號於二期作晚植的產量(6,182.8，6,013.7 $kgha^{-1}$) 較高而化學組成（直鏈澱粉、糖類等）的含量較高。秈型臺中秈10號早植則是高產 (6,208.8，6,136.5$kgha^{-1}$) 與低化學組成含量，一期作兩品種在早移植期之下出現高產量（臺農67號6,386.5 $kgha^{-1}$，臺中秈10號6,328.7 $kgha^{-1}$），而在早移植之下化學組成（粗蛋白及灰分）之含量則亦較高。經統計分析，一、二期作兩品種（臺農67號、臺中秈10號）之不同移植期處理對產量性狀或化學組成的影響，皆呈現極顯著性差異，品種間亦大部份出現顯著性差異。一、二期作兩品種之產量、化學組成與氣象因子呈現高的相關，氣象因子如X_1（累積溫度），X_2（平均溫度），X_5（日射量）及X_7（平均雨量）。一期作臺農67號與臺中秈10號在分蘗期間之氣象因子與產量之關係，分別爲Y_1（產量$kgha^{-1}$）= 60.15 + 0.42 * X_2（均溫）及Y_1 = 55.76 + 0.57 * X_2，而二期作則各爲Y_1 = 32.72 - 0.91 ** X_2與Y_1 = 54.62 + 0.81 ** X_2。一期作穀粒充實期間之氣象因子與台農67號及台中秈10號之直鏈澱粉含量 (Y_2: %) 之關係式各爲Y_2 = 78.26-0.93 ** X_2與Y_2 = 12.68 - 8.81 * X_2。而二期作臺農67號及臺中秈10號之關係式分別爲Y_2 = 10.32-0.85 ** X_1與Y_2 = 6.26 - 0.65 * X_1。

關鍵詞：氣象因子、化學組成、水稻、產量。

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